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Responses and Effects of UV-B

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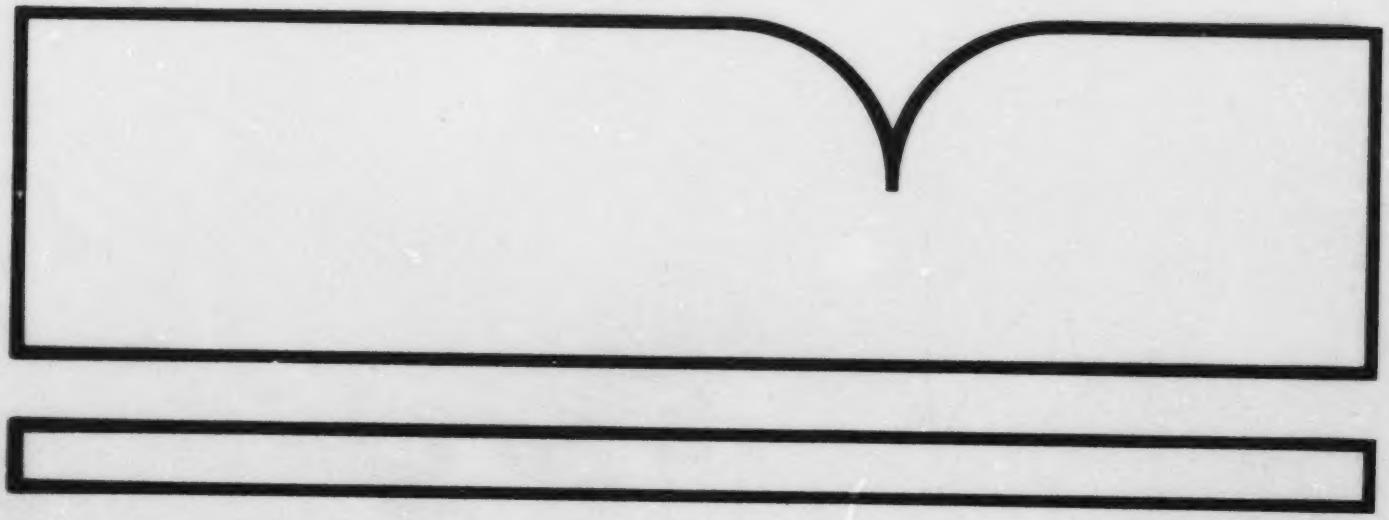

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16. ABSTRACT

Potential stratospheric ozone perturbations following a nuclear war would be highly dependent on the yield of the individual explosions. The senario involving mainly high-yield nuclear weapons described in Vol. I yields a maximum ozone column depletion of 44% after 6 months. Scenarios involving lower yield weapons would produce little stratospheric ozone reduction. As calculated with simple one-dimensional models assuming an unperturbed climate, maximum ozone depletion would be reached in 6-12 months, and a depletion of at least 10% could persist for about 3 to 6 years for the high-yield scenario. The effectively instantaneous meridional and longitudinal spreading that occurs in the one-dimensional model utilized in these calculations may underestimate ozone reduction in the Northern mid-latitudes for the first few months, when the injected NO_x would remain peaked over the involved areas. Increases in ultraviolet flux at the surface would depend on latitude and season, and absorption by intervening clouds of smoke and other species. Until the smoke substantially cleared, the UV-B flux could not significantly increase at the surface, even for large ozone reductions. Changes in stratospheric ozone concentrations by chemical reactions with nitrogen oxides and by smoke-induced temperature and circulation changes could affect recovery time of the atmosphere, even after smoke particles were removed.

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3.2 RESPONSES AND EFFECTS OF UV-B [1]

3.2.1 Introduction

Potential stratospheric ozone perturbations following a nuclear war would be highly dependent on the yield of the individual explosions. The scenario involving mainly high-yield nuclear weapons described in Volume I yields a maximum ozone column depletion of 44% after six months. Scenarios involving lower yield weapons (e.g., Ambio, 1982) would produce little stratospheric ozone reduction. As calculated with simple one-dimensional models assuming an unperturbed climate, maximum ozone depletion would be reached in 6 to 12 months, and a depletion of at least 10% could persist for about three to six years for the high-yield scenario. The effectively instantaneous meridional and longitudinal spreading that occurs in the one-dimensional model utilized in these calculations may underestimate ozone reduction in the Northern mid-latitudes for the first few months, when the injected NO_x would remain peaked over the involved areas. Increases in ultraviolet flux at the surface would depend on latitude and season, and absorption by intervening clouds of smoke and other species. Until the smoke substantially cleared, the UV-B flux could not significantly increase at the surface, even for large ozone reductions. Changes in stratospheric ozone concentrations by chemical reactions with nitrogen oxides and by smoke-induced temperature and circulation changes could affect the recovery time of the atmosphere, even after smoke particles were removed (Pittock et al., 1985).

Stratospheric ozone currently functions effectively as an ultraviolet screen by filtering out solar insolation in the ultraviolet wavelengths as it passes through the stratosphere, thus allowing only small amounts of the longer wavelengths of UV radiation to leak through to the surface of the Earth. Although currently this radiation comprises only a minute fraction (less than 1%) of the total solar spectrum, it can have a major impact on biological systems because of its actinic nature. There would be several biospheric consequences of increased levels of solar UV-B radiation (i.e., light in the 280–320 nm band) reaching the surface of the Earth.

[1] This section written by R. Worrest.

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Many organic molecules, most notably DNA and proteins, absorb UV-B radiation, which can initiate photochemical reactions. Most of the known biological effects of UV-B radiation are damaging, and the defense mechanisms that serve to protect both plants and animals from current levels of UV-B radiation are quite varied. These mechanisms might not suffice under conditions of the extreme levels of UV-B radiation that could follow a nuclear war. It should also be remembered that UV-B levels differ both latitudinally and altitudinally, with the highest exposures at the tropics or at high altitudes. The current difference between the extremes of exposures is about 3- to 6-fold, but biota are presently adapted to the levels that are normally experienced at their locations.

3.2.2 Biological Sensitivity Functions

The biological response to ultraviolet radiation can be very wavelength dependent. This wavelength specificity makes it necessary to develop weighting functions to express ultraviolet radiation in biologically meaningful terms (Caldwell, 1981). Biological action spectra normally serve as the basis for these weighting functions.

A generalized equation to describe the use of a biological weighting function is:

$$I_e = \int I_\lambda \cdot E_\lambda \cdot d\lambda \tag{3.1}$$

where:

I_e = effective irradiance

I_λ = spectral irradiance

E_λ = relative effectiveness of irradiance at wavelength λ to elicit a particular biological response.

The weighting function is normally taken as an action spectrum for a particular biological response. Several action spectra have been developed describing the response of biological systems to UV-B radiation (Figure 3.1). Examples are a representation of a DNA response as described by Setlow (1974), a generalized plant response (Caldwell, 1968), an erythemal action spectrum (Nachtwey and Rundel, 1981), and a photoinhibition response for plant photosynthesis (Jones and Kok, 1966).

Based on an analytic characterization of ultraviolet skylight by Green et al. (1980), a 40% ozone reduction at 45°N latitude would only result in a 5% increase in total solar ultraviolet (between 290 nm and 360 nm) daily flux. This would be of minimal consequence if radiation throughout the 290–360 nm waveband were of equal biological effectiveness. However, when the biological weighting functions based on the action spectra are

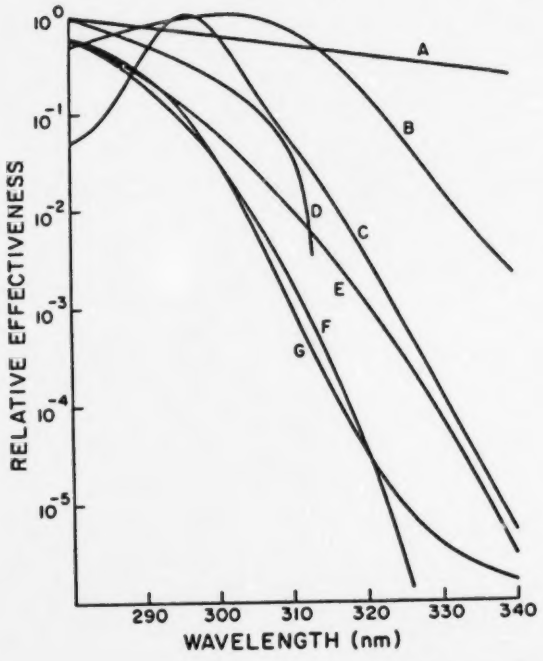

Figure 3.1 Plots of several action spectra used as weighting function for assessing the biological impact of UV-B radiation. From Worrest (1983). A. Photoinhibition action spectrum (Jones and Kok, 1966); B. Robertson–Berger Meter; C. erythema; D. Caldwell's (1968) generalized plant action spectrum; E. A721, used at the University of Florida; F. A79, used by the U.S.D.A. Agricultural Research Center, Beltsville, MD; G. generalized DNA action spectrum (Setlow, 1974)

employed, a very different picture emerges. Based on the DNA response described by Setlow (1974), a 40% ozone decrease would result in a 213% increase in biologically effective radiation (DNA damage). The generalized plant response would increase by 132% (plant damage) (Table 3. 1).

TABLE 3.1

RELATIONSHIP BETWEEN OZONE DEPLETION AND BIOLOGICAL EFFECTIVENESS OF INCREASED UV-B[a]

Ozone Decrease	Ultraviolet Increase		Increase in Biological Effectiveness	
	290-320 nm	320-360 nm	DNA	Plant
10%	8%	0.4%	28%	21%
20%	17%	0.8%	67%	49%
30%	27%	1.2%	125%	85%
40%	38%	1.6%	213%	132%

[a] Increase in absolute and biologically effective ultraviolet daily irradiance at the surface of the Earth associated with various levels of stratospheric ozone depletion. Absolute irradiance is based on a model by Green et al. (1980) [45°N latitude at the summer solstice; 20-year average ozone thickness at this latitude and date = 0.338 cm]. DNA action spectrum based on Setlow (1974), and plant action spectrum based on Caldwell (1968). Action spectra referenced to 300 nm = 1.00

3.2.3 Effects on Terrestrial Plants

Terrestrial plants (in non-arid zones) have evolved to maximize exposure of their photosynthetic tissues. Therefore, these tissues are concomitantly exposed to the potential stress of solar ultraviolet radiation. Many studies have demonstrated that photosynthesis is inhibited by UV-B radiation. In addition, it has been shown that UV-B radiation can affect leaf expansion, abscisic acid content, pigment concentrations, plant growth, carbohydrate metabolism, fruit growth and yield, pollen germination, and pollen tube growth (Caldwell, 1981; Teramura, 1982; Teramura, 1983).

Of primary importance to humans in the months following a nuclear war could be the effect of ultraviolet radiation on total yield of crop species.

The effect of UV-B radiation on the yield of several crop species has been studied. One series of experiments relevant to the ozone depletion problem is the research by Teramura (1983). Although the results were variable across years, significant reductions in crop yield following exposure to UV-B radiation simulating 16% and 25% ozone depletion were found for two cultivars of soybean (range of reductions, 14–25%). Not only was the total yield reduced but protein concentrations declined by as much as 5% in one cultivar during two years of the study, and seed lipid concentrations were reduced by 3–5% in another cultivar.

As the atmospheric particulates were gradually removed in the weeks and months following a major nuclear war, plants would become exposed to enhanced levels of UV-B radiation. Because of the long recovery time of the ozone layer, the ratio of UV-B radiation to photosynthetically active radiation would be far greater than normal as the atmosphere cleared. In studies involving soybean plants, it was found that supplemental UV-B radiation adversely affected net photosynthesis and some growth parameters when the exposure occurred concurrently with low levels of photosynthetically active radiation (Teramura, 1980; Biggs et al., 1981; Teramura, 1982).

There are other problems that arise in plants following exposure to high levels of UV-B radiation. Flint and Caldwell (1984) found that 2- to 3-fold increases in biologically effective ultraviolet radiation were sufficient to inhibit pollen germination. A more subtle effect of UV-B radiation might be on the timing of the flowering of plants. The results of recent experiments have demonstrated that UV-B radiation can have either an inhibitory or stimulatory effect on flowering, depending on plant species, growth conditions, and other factors (Caldwell, 1968; Biggs and Basiouny, 1975; Biggs and Kossuth, 1978; Mirecki and Teramura, 1984). Whether UV-B radiation directly influences flowering events or plays an indirect role through changes in photosynthate reserves is not yet known.

Some plant species apparently acclimatize to enhanced levels of UV-B radiation. Although the ozone thickness in the tropics is significantly less than at temperate latitudes and ambient levels of UV-B irradiance are much higher, temperate-zone alpine species exist at high elevations in the tropics (Robberecht et al., 1980; Caldwell et al., 1980). Such species are exposed to a wide range of UV-B levels over their geographical ranges. There are inherent differences in sensitivity of the photosynthetic system to UV-B radiation damage that have been demonstrated for species of the same genus, or even races of the same species, which occur in different locations on the latitudinal gradient of the arctic-alpine life zone (Caldwell et al., 1982). If acclimatization to environments with high ultraviolet exposure levels is merely a phenotypic response, the plants might be able to cope with small increases in UV-B irradiance. If, on the other hand, acclimatization involves genotypic change for some species, the heterogeneity of the gene pool would

influence the population-level adaptability to the enhanced UV-B following a nuclear war.

Plant resistance to a change in an environmental parameter is, in part, a genotypically controlled, species-specific characteristic (Levitt, 1980). An alteration of an environmental stress could thus lead to a change in the competitive balance of the plant community resulting from inherent differences in plant resistance. Many plants have been shown to exhibit a wide range of sensitivity to enhanced UV-B radiation (Teramura, 1983). Since UV-B radiation can be considered as an environmental stress, any increase in UV irradiance could lead to changes in competitive ability within plant communities through differential resistance of the competing species (Caldwell, 1977). Competition could occur within the same species (intraspecific) or between different species (interspecific).

Intraspecific competition becomes increasingly important in monospecific communities such as agricultural systems. On the other hand, in natural ecosystems with high species diversity, interspecific competition predominates. In agricultural systems, interspecific competition could also be important between a crop and weed species. Total harvestable yield, as well as its quality, can be altered by the presence of weeds. Because of the subtle nature of UV-B-radiation stress, an enhancement of solar UV-B radiation might alter the competitive balance of plants indirectly more than directly, permanently reducing ecosystem primary productivity. The results of Gold and Caldwell (1983) and Fox and Caldwell (1978) support this hypothesis.

In natural ecosystems, although the total productivity might not be permanently altered as a consequence of increased UV-B radiation, a shift could occur in species composition. Because of the shifts in competitive balance, increasing solar UV-B radiation would pose a considerable risk both to agricultural as well as natural ecosystems. In agricultural systems, any increase in weed competitiveness would certainly result in reduction in actual harvestable crop yields, a lowering of crop quality, or an alteration in disease or pest sensitivity. Presumably, more UV-B-tolerant species would proliferate at the expense of the sensitive ones. Changes in the competitive balance of native species could also have profound effects on natural ecosystems. Even very subtle differences in sensitivity could result in large changes in species composition over time and possibly affect ecosystem function.

3.2.4 Effects on Marine Ecosystems

The euphotic zone, i.e., those depths with light levels sufficient for net photosynthesis to be positive, is frequently taken as the water column down to the depth at which there is 1% of the surface photosynthetically active radiation. In marine ecosystems, UV-B radiation penetrates approximately the upper 10% of the coastal euphotic zone before it is reduced to 1% of its

surface irradiance (Jerlov, 1976). Penetration of UV-B radiation into natural waters is a key variable in assessing the potential impact of this light on any aquatic ecosystem. The calculations of the penetration of UV-B radiation and biologically effective dose rates in natural waters has been described in detail (Smith and Baker, 1982; Baker and Smith, 1982a,b). Based on the data, it has been calculated that near the surface of the ocean, enhanced UV-B radiation simulating a 25% reduction in ozone concentration would cause a decrease in production by about 35% (Smith and Baker, 1982). The estimated reduction in production for the whole euphotic zone would be about 10%. These calculations were based on attenuation lengths, i.e., the product of depth in the water column and the diffuse attenuation coefficient of the water. Therefore, waters of various turbidities and absorption characteristics could be compared, a factor that must be considered when dealing with the turbid environment of coastal areas caused by potential post-war storms.

The amount of UV-B radiation reaching the ocean's surface has long been suspected as a factor influencing primary production (Steeman-Nielsen, 1964; Jitts et al., 1976; Lorenzen, 1979; Smith et al., 1980; Thomson et al., 1980; Worrest et al., 1980). Research shows convincingly that ultraviolet radiation, at present levels incident at the surface of natural bodies of water, has an influence on phytoplankton productivity. If one assumes that current phytoplankton populations sense and control their average vertical position in such a way as to limit UV-B exposure to a tolerable level, then a 10% increase in solar UV-B exposure would necessitate a downward movement of the average position, thereby reducing the average UV-B exposure by 10%. There would be a corresponding reduction of light available for photosynthesis at the increased depths, and the magnitude of visible light loss would be proportional to the ratio of the absorption coefficient of photosynthetically active radiation (PAR) divided by the absorption coefficient of UV-B radiation. The percentage loss of PAR would always be less than the percentage change in UV-B radiation. The loss of PAR in many locations might not be significant. However, in some very productive areas, especially high latitude ocean areas, PAR is the primary limiting factor on marine productivity (Russell-Hunter, 1970). From optical measurements, Calkins (1982) estimated the PAR loss to be in the range of 2.5–5% for a 10% UV-B increase.

In addition, the sensitivity of various species of phytoplankton to UV-B radiation differs: a difference that would result in shifts in community composition following changes in exposure to UV-B radiation (Worrest et al., 1981a,b). One effect of enhanced levels of UV-B radiation would be to alter the size distribution of the component producers in a marine ecosystem. Increasing or decreasing the size of the representative primary producers upon which consumers graze can significantly increase the energy allotment

required for consumption, thereby reducing the feeding efficiency of the consumer. In addition, the food quality of the producers is altered by exposure to UV-B radiation. Döhler (1982) demonstrated that protein content, dry weight, and pigment concentration are all depressed by enhanced levels of UV-B radiation.

The impact on marine fisheries as a food supply to humans would be significant if the species that adapted to enhanced UV-B radiation were of different nutritional value (i.e., if they altered growth and fecundity of the consumers or different accessibility to human survivors). If the indirect impact of suppression upon consumers were linear, a 10% reduction of primary production would result in a 10% reduction in fish production. A question still under investigation is whether the trophodynamic relationships might be non-linear. For example, there may be an amplification factor involved that results in a relatively greater impact at higher trophic levels than at the primary-producer level. In the type of example described by Worrest (1983), a 10% reduction in energy transfer efficiency would result in a 27% reduction in fish-food production.

Zooplankton are critical components in typical aquatic food webs which lead to larger animals, including those comprising human food fisheries. Zooplankton contain nearly all groups of aquatic animals, at least for some phase in their life history, such as the egg or larval stage. Many zooplankton species normally live very close to the surface, even in daylight, while others occupy the near-surface layer during only part of their life cycle. The near-surface layer is a very important zone in the interactions of the physical/chemical/biological components of aquatic systems. Investigators have reported that the effect of increased UV-B radiation on some marine zooplankton (e.g., copepods, shrimp larvae, crab larvae) is to increase the mortality of the organisms and to decrease the fecundity of the survivors (Karanas et al., 1979; Damkaer et al., 1980; Damkaer et al., 1981; Karanas et al., 1981; Damkaer and Dey, 1983). Regardless of the cellular-level responses to ultraviolet irradiation, it is usually noted that up to some level of exposure, there is no apparent effect on the organism. However, once this threshold is exceeded, either the repair systems themselves become inactivated by the radiation, or the damage to the general tissues is beyond the capacity of the repair systems. The apparent thresholds are near current incident ultraviolet levels.

Damkaer et al. (1981) compared the estimated effective ultraviolet daily doses under various ozone reductions with survival thresholds. A 40% ozone reduction significantly reduces the window of safety at the beginning of the zooplankton near-surface season. Whether or not the populations could endure a drastically reduced time at the near-surface waters is not known. Success of any year-class depends on the timing of a great number of other events in addition to levels of exposure to UV-B radiation.

The direct effect of UV-B radiation on food-fish larvae closely parallels the effect on zooplankton. There is an implication in some review papers (e.g., Hunter et al., 1981, 1982; NRC, 1984) that UV-B damage would be overcome by the maximally functioning photo-repair mechanism. Up to some level (daily-dose threshold) this is probably true, but near-surface exposure levels would exceed threshold levels following the washout of particulate material caused by a nuclear war. Hunter et al. (1982) realized that information is required on seasonal abundances and vertical distributions of fish larvae, vertical mixing, and penetration of UV-B into appropriate water columns before effects of incident or increased levels of exposure to UV-B radiation can be predicted. For March through October, with the larvae described by Hunter et al. (1981) and with a 10 m mixing layer, a 10% increase in incident UV-B radiation would not exceed threshold doses in less than 20 days. With a 20% increase in incident UV-B radiation, however, the depth of the threshold dose-rate is increased. In the dose/dose-rate threshold model, all of the larvae within a 10 m mixed layer in April and August would be killed after 15 days. It was calculated that about 8% of the annual larval population throughout the entire water column would be directly killed by a 20% increase in exposure to UV-B radiation. For models with increased mixing, to 15 m, there is no predicted effect until UV-B radiation increases by 50%, and no additional loss beyond that level with a 60% increase.

3.2.5 Effects on Human Health

Human health is influenced by UV radiation in many ways; for example, by the formation of vitamin D, sunburn, eye diseases, immunological changes, photoallergic reactions, and skin diseases, including skin cancer. Skin cancer stands out as one problem that increases with increased UV-B radiation. The severity of the health and other biological effects of radiation depend on its spectral composition, irradiance, and exposure time. UV-B radiation has been demonstrated, in many instances, to be several orders of magnitude more biologically effective than UV-A radiation.

Epidemiological studies have shown that the incidence of non-melanoma skin cancer correlates with exposure to sunlight. While non-melanoma skin cancers occur in people of all skin types, the incidence is highest in light-skinned people. In patients with *Xeroderma pigmentosum* (a rare recessive genetic disorder), who have increased susceptibility to skin cancer, there is reduced repair of DNA damage caused by UV-B radiation. Animal experiments have revealed that UV-B radiation is the most effective wavelength region for carcinogenesis by UV radiation. These data indicate that increased incidence of non-melanoma skin cancer could be expected from increased UV-B irradiance.

Non-melanoma skin cancer is exceptional among the biological effects

of UV-B in that statistics are available. Studies indicate that, apart from the radiation amplification, biological amplifications exist for the particular biological effects. Specifically, with unchanged exposure habits, for every 1% decrease in total ozone, the incidence of basal cell carcinomas increases by 2% to 4% and the incidence of squamous cell carcinomas increases by 3% to 8%. Although the incidence of squamous cell carcinoma is only about 20% of the total, it is more invasive and lethal than basal cell carcinoma. While these conditions can usually be treated effectively if medical help is available, they currently still result in thousands of deaths per year. In the United States, there are approximately 500,000 new cases of non-melanoma skin cancer per year, and the total annual number of deaths, about 5000, is comparable to the annual total for malignant melanoma. Mortality rates would be higher in the absence of medical attention, a likely situation after a large-scale nuclear war.

There are several indications that sunlight may also be one of the causative factors in the pathogenesis of malignant melanoma, which affects people of all skin types. These indications come from epidemiological and clinical observations which, because they deal with exposure to total sunlight, do not point to any particular wavelength range in the solar spectrum. In cases where UV-B radiation is involved, a decrease in stratospheric ozone might be expected to increase the incidence of melanoma. In some types, such as *Lentigo melanoma* and in melanoma arising in patients with *Xeroderma pigmentosum*, the relationship to sunlight is relatively clear. In other cases, the evidence is circumstantial. The incidence of malignant melanoma in patients with *Xeroderma pigmentosum* suggests that, at least in these cases, UV-B radiation is involved.

UV-B radiation has been shown to alter several responses of the immunological system. UV-B radiation has been reported to depress delayed hypersensitivity responses in human skin. It causes reduction in the number of Langerhans cells in human skin, and induces alterations in the distribution and function of subpopulations of circulating lymphocytes in humans. Effects of UV-B radiation on the immunological system diminish the ability of a mouse to reject a transplanted tumor induced by UV-B radiation in another mouse. UV-B radiation also impedes the ability of a mouse to reject tumors initiated by UV-B radiation in its own skin. The doses of UV-B radiation causing these immunological changes are much smaller than the doses which induce tumors. A primary concern is the possibility that these immunological changes may contribute to the development of malignant melanoma in humans, especially as the immunological changes are caused mainly by the shortest wavelengths in sunlight.

Overall, although the effects of enhanced exposures to UV-B would not be as severe as the effects of acute climatic disturbances on agricultural and natural ecosystems, it seems likely that significant, adverse biological

effects would occur. In marine ecosystems, there could be substantial effects on phytoplankton and zooplankton productivity and composition. Human health effects could also be expected, including increased incidences of eye disease and various forms of skin cancer.

3.3 ATMOSPHERIC POLLUTANTS

3.3.1 Introduction

As a consequence of a major nuclear war, large quantities of various gases and particulate pollutants would be generated, both from the bursts themselves and from the burning of cities, fuel depots, and natural vegetation and crops over a period of days to weeks (Volume I). These pollutants would include various oxides of nitrogen, sulphur dioxide, ozone, hydrochloric acid, cyanides, photochemical oxidants, pyrotoxins, and hydrocarbons. Carbon monoxide would also be generated in large quantities from low temperature, persistent fires. Around the edge of the particulate-laden smoke clouds, oxidation of hydrocarbons with NO_x could result in the production of photochemical oxidants, such as peroxy acetylnitrate (PAN). Massive amounts of particulate matter could be transported from centers of combustion, and the expanding forest and grassland fires could add to this load for weeks. The dust and bomb debris deposited from nuclear weapon bursts would deposit radioactive material both locally and, eventually, globally. Particulates from combustion would deposit soot, hydrocarbons, sulphates, ammonia, and elements from burning vegetation and fuels. Large quantities of manganese, cadmium, copper, cobalt, nickel, and arsenic would be transported from cities and eventually be deposited in downwind locations.

The quantities and distribution of pollutants over time are dealt with to some extent in Volume I, and by Crutzen and Birks (1982) and NRC (1985). Svirezhev et al. (1985) considered a worst-case scenario, suggesting that large quantities of NO_x would be produced, as well as SO_2 and sulphate. They suggested that rain events of pH 2.4 could continue for a number of weeks over mid-latitudes in the Northern Hemisphere. Volume I authors, using a much less severe scenario, suggested perhaps two weeks of rains of approximately pH 3.0. NO_x, O_3, and photooxidants would be released from combustion, and smoldering fires would generate large quantities of CO.

In the discussion that follows, we assume that the Northern Hemisphere, especially in the mid-latitudes, would be exposed to elevated levels of these pollutants, recognizing that there are very large uncertainties as to concentrations and spatial and temporal patterns of each of the pollutants. Relatively little attention has yet been paid to quantification of them and even less to exposures that would be experienced by human survivors and by agricultural crops, livestock, and natural ecosystems. This is an area requiring